Figure 11. Technology Development Timeline: Milestones and Decision Points[a]

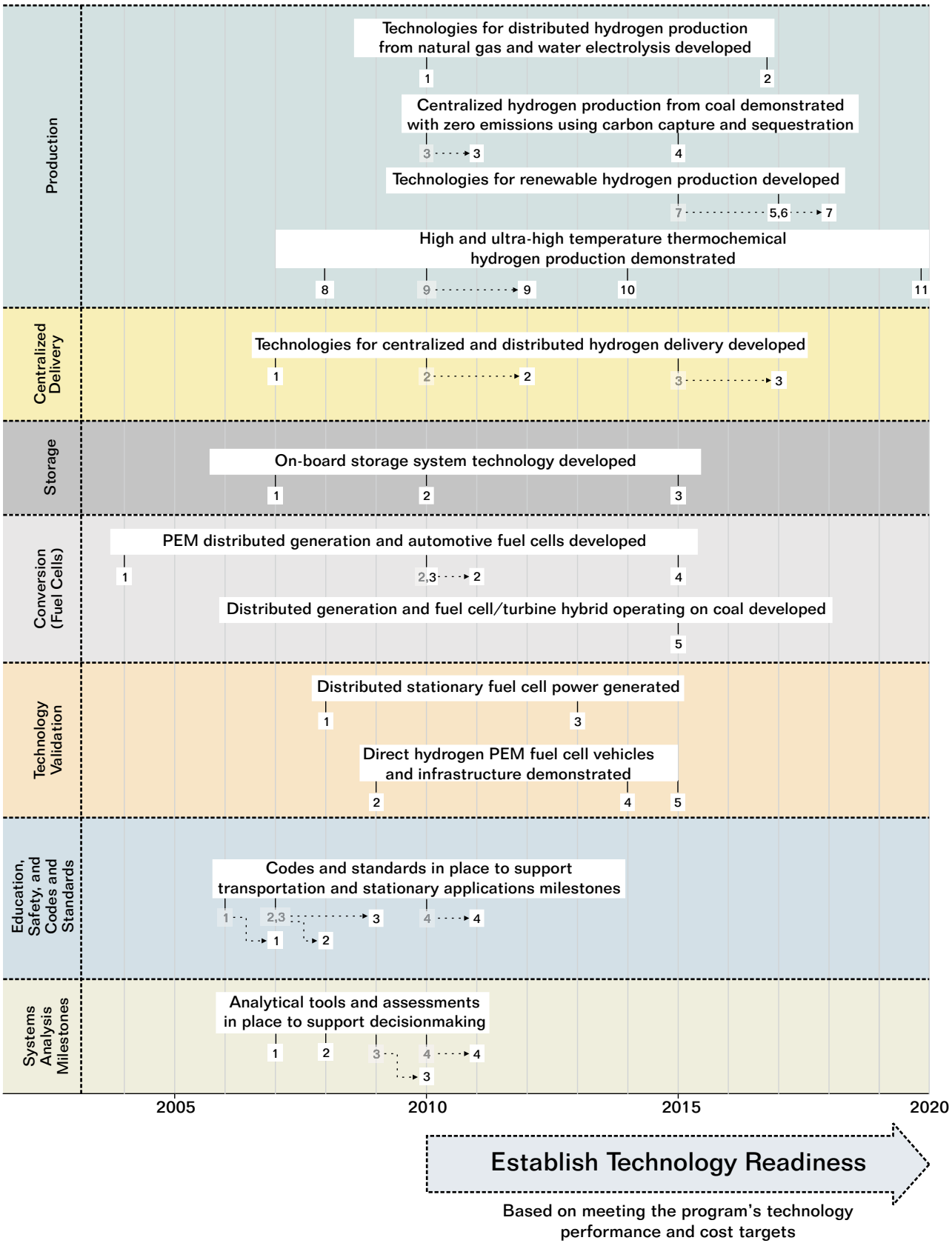

Figure 11 (cont'd). Legend for Technology Development Timeline[a]

Production Milestones[b]

Distributed Natural Gas and Electrolysis

1. 2010: Develop technology to produce hydrogen from natural gas at a refueling station that projects to a cost of $2.50/gge for hydrogen. [At the pump, untaxed, at 5,000 psig]
2. 2017: Develop technology to produce hydrogen utilizing distributed electrolysis that projects to a cost of <$3.00/gge. [At the pump, untaxed, at 10,000 psig]

Central Coal[c, d]

3. 2010 → 2011: Develop pre-engineering membrane separation modules and reactors for hydrogen production that meet membrane cost target of $150-200/ft^2
4. 2015: Demonstrate a near-zero atmospheric emission coal plant producing hydrogen and power with carbon capture and sequestration at a 25% cost reduction that projects to $0.80/gge at the plant gate (ultimate target: $1.80/gge delivered)

Renewable Resources[e]

5. 2017: Develop technology to produce hydrogen through distributed reforming of renewable liquid fuels at a refueling station that projects to a cost of <$3.00/gge for hydrogen [At the pump, untaxed, at 10,000 psig]
6. 2017: Develop technology for central hydrogen production integrating wind electricity production and electrolysis that projects to a cost of <$2.00/gge at the plant gate (<$3.00/gge delivered)
7. 2015 → 2018: Demonstrate laboratory-scale photobiological water splitting system to produce hydrogen at an energy efficiency of 5% (solar-to-hydrogen). Demonstrate laboratory-scale photoelectrochemical water splitting system to produce hydrogen at an energy efficiency of 10% (solar-to-hydrogen)

High-Temperature Thermochemical[f]

8. 2007 → 2008: Operate laboratory-scale thermochemical and electrolytic processes to determine the feasibility of coupling them with a nuclear reactor
9. 2010 → 2012: Laboratory-scale demonstration of solar-driven high-temperature thermochemical hydrogen production that projects to a cost $6.00/gge (ultimate target: $7.00/gge delivered)
10. 2011 → 2014: Pilot-scale demonstration of thermochemical hydrogen production system for use with nuclear reactors that projects to a cost of $2.50/gge (ultimate target: $3.50/gge delivered)
11. 2017 → 2020: Engineering-scale demonstration of thermochemical hydrogen production system for use with nuclear reactors that projects to a cost less than $2.00/gge ($3.00/gge delivered)

Storage Milestones

1. 2007: Downselect hydrogen storage options with potential to meet 2010 targets
2. 2010: Develop and verify on-board storage systems achieving: 6% by weight capacity and 1,500 watt hours/liter energy density at a cost of $4.00/kWh of stored energy
3. 2015: Develop and verify on-board storage systems achieving: 9% by weight capacity, 2,700 watt hours/ liter, and $2.00/kWh

Validation Milestones

1. 2008: Validate stationary fuel cell system that co-produces hydrogen and electricity at 20,000 hours durability with 32% efficiency at a cost of $1500/kW or less
2. 2009: Validate polymer electrolyte membrane fuel cell vehicles at multiple sites, achieving 2,000 hours durability, a 250-mile range, and $3.00/gge of hydrogen
3. 2013: Validate stationary fuel cell system that co-produces hydrogen and electricity at 40,000 hours durability with 40% efficiency at a cost of $750/kW or less
4. 2014: Validate PEM fuel cells on operational vehicles in different climatic conditions that can be produced for $45/kW when produced in quantities of 500,000
5. 2015: Validate polymer electrolyte membrane fuel cell vehicles achieving 5,000 hours durability (service life of vehicle) and a 300-mile range

Conversion Milestones[e]

1. 2004: Decision to discontinue on-board fuel processing based on inability to achieve 78% efficiency and <0.5 minute start time
2. 2010 → 2011: Distributed stationary generation natural gas/propane 5-250 kW fuel cell go/no-go decision based on ability to achieve: 40% electrical efficiency, 40,000 hours durability (equivalent to service life between major overhauls), at a cost of less than $400-$750/kW (depending on application)
3. 2010: Develop direct hydrogen polymer electrolyte membrane automotive fuel cell operating at 60% peak efficiency, 220 W/L density, 325 W/kg specific power at a cost of $45/kW (automotive production quantity)
4. 2015: Polymer electrolyte membrane automotive fuel cell meets cost of $30/kW
5. 2015: Fuel cell/turbine hybrid operating on coal developed at a cost of $400/kW with a HHV efficiency of 50% with carbon sequestration

Education, Safety, and Codes and Standards Milestones[e]

1. 2006 → 2007: Facilitate publishing domestic and international hydrogen quality standards and publish initial set of basic safety training materials
2. 2007 → 2008: Publish initial Best Practices manual for hydrogen safety
3. 2007 → 2009: Education program for safety and code officials in place
4. 2010 → 2012: Initial set of technical codes and standards in place to support demonstrations, commercialization decisions and regulatory standards

Centralized Delivery Milestones[e]

1. 2007: Define the criteria for a cost-effective hydrogen fuel delivery infrastructure for supporting the introduction and long-term use of hydrogen for transportation and stationary power
2. 2010 → 2012: Develop technologies to reduce the cost of hydrogen fuel delivery from the point of production to the point of use in vehicles or stationary power units to <$1.70/gge of hydrogen
3. 2015 → 2017: Develop technologies to reduce the cost of hydrogen fuel delivery from the point of production to the point of use in vehicles or stationary power units to <$1.00/gge of hydrogen

Systems Analysis Milestones[e]

1. 2007: Develop transition scenarios for infrastructure and hydrogen resources for a hydrogen economy
2. 2008: Develop a macro-system model of the hydrogen fuel infrastructure to support the transportation system
3. 2009 → 2010: Complete assessment of hydrogen quality requirements for production, delivery, storage and fuel cell pathway
4. 2010 → 2011: Develop electricity infrastructure module for the macro-system model

[a] *Achieving the milestones is dependent on requesting and receiving funding at the Hydrogen Program planning levels for each office.*

[b] *The hydrogen cost milestones are not yet normalized across the Hydrogen Program. The Program is in the process of normalizing the criteria used to determine the Hydrogen Program cost goals using the recently-developed "H2A" modeling tool.*

[c] *The assumed feedstock cost for coal is $29.00/short ton.*

[d] *Milestone delay due to changes in Fossil Energy program planning.*

[e] *Milestone delays are due to shortfalls in appropriations.*

[f] *Milestone delays are due to changes in the DOE budget planning profile.*